Unbalanced Radial Force and Vibration Mode Analysis of Large Interior Permanent Magnet Machines with Static, Dynamic and Mixed Air-gap Eccentricity

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Abstract — The purpose of this paper is to provide the radial force and vibration mode comparison between two large interior permanent magnet machines (IPM) with different pole-slot combination considering stator and rotor eccentricity. Due to the punching tolerance, the mixed eccentricity of air-gap is inevitable. It will generate the asymmetric magnetic flux density in air-gap, which makes the unbalanced magnetic pull and vibration. The study is focused on the unbalanced radial force and vibration mode according to eccentricity condition such as static, dynamic and mixed. When the high vibration is produced especially resonance, the obtained results provide a clue what eccentricity condition occurs in the machine.

I. INTRODUCTION

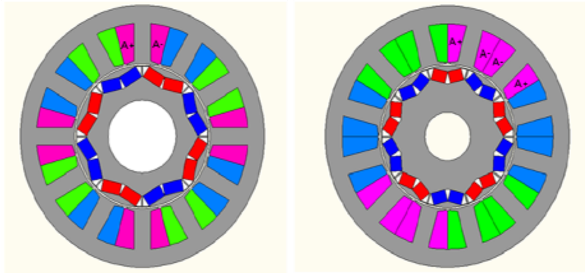
In comparison to surface-mounted PM (SPM) motors, IPM motors are a more attractive option for various applications because of their high torque density, wide speed range, excellent efficiency, and robustness [1].

However, the radial force between stator and rotor is relatively high, so the unbalanced magnetic forces affect significantly the vibration mode when the stator and rotor eccentricity occurs. The asymmetric magnetic flux density due to eccentricity generates the unbalanced magnetic force which is global magnetic force of rotor. This force generates the vibration in rotational structure of machine [5], but it is focused on the asymmetric phase winding. Unbalanced magnetic force due to eccentricity is studied [4], but is for the outer rotor SPM type machine according to slot angle etc. Several studies [2-3] deal many kinds of slot combination and analytical method.

In this paper, the unbalanced magnetic forces of large IPM due to static, dynamic and mixed eccentricity are analyzed by 2D FEA. The comparison study between 8 pole-12 slot and 10 pole-12 slot IPM machines for ship application is also presented. The dynamic eccentricities due to rotor run-out according to magnet pole position are investigated.

II. MODELING OF ECCENTRICITY

Fig.1 shows the cross section of the analysis models to comparison study. Fig.2 presents modeling of static, dynamic and mixed eccentric of air-gap. The stator inner diameter is shifted 0.5mm to consider static eccentricity. The rotor out diameter is also moved to make dynamic eccentricity. The several kinds of rotor dynamic eccentricity position are considered because the rotor of IPM has salient magnetic structure. The mixed eccentricity means the stator and rotor eccentricity occur simultaneously. The maximum permitted air-gap eccentricity is assumed 0.5(mm) and average air-gap length is 2.0(mm).



(a) 8 Pole-12 Slot *(b) 10 Pole-12 Slot*

Fig. 1. Cross section of comparative models

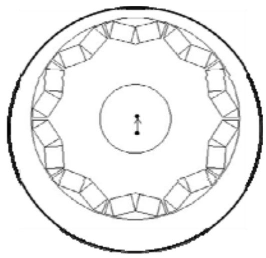
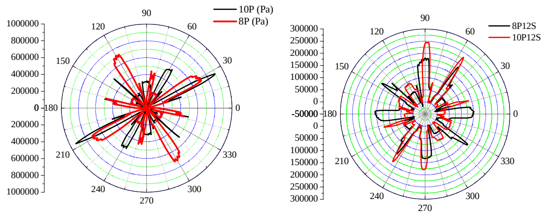


Fig. 2. Modeling of eccentricity

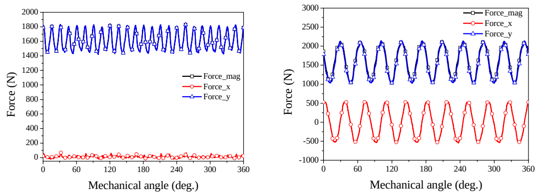
III. ANALYSIS RESULTS

The radial magnetic force at air-gap is calculated by 2D FEA. The full model is used to consider the eccentricity condition. The global force applied to rotor is computed by maxwell stress tensor method on air-gap contour. After computing the radial and tangential components of force at contour, their components (Fx, Fy) are summed themselves. Fig. 3 shows the space radial force distribution in air-gap at specific time. The 8 pole-12 slot machine has four directional forces whereas the 10 pole-12 slot machine has two. The unbalance of space radial stress in air-gap is displayed when the stator inner diameter is shifted to y-direction which is called static eccentricity. The unbalanced magnetic force and their harmonic components based on mechanical frequency due to static eccentricity are presented in fig. 4. Because each rotor pole meets the narrow air-gap, the global force fluctuation produced in rotor has same number as pole. The main harmonics of 8 pole-12 slot machine is 24X component due to the combination of armature reaction field. Fig. 5 shows the analysis results of dynamic eccentricity. The magnitude of force is almost same as static eccentricity. When the dynamic eccentricity occurs, the narrow air-gap made by rotor shift rotate and then it meets the 12 teeth. The 10 pole-12 slot machine has 12X component of unbalanced force, whereas the 8 pole-12 slot machine has 24X. The result of Fx and Fy shows that the direction of force rotates also. Fig. 6 shows the unbalanced force when the mixed eccentricity occurs. The 10 pole-12 slot machine has more harmonic components than the 8 pole-12 slot machine. The 2X component is very high because the shifted rotor out diameter meets the shifted stator inner diameter when the rotor rotates. The attractive force level is relatively low but the frequency characteristics changed such as 2X component. The air-gap eccentricity is inevitable in actual case. The punching tolerance make the run-out of core structure and the static, dynamic and mixed eccentricity occurs. Manufactures can control the maximum air-gap distortion, so we can assume the possible eccentricity condition. The extended paper will deals the details of unbalanced force characteristics and can provide the relationship between eccentricity and vibration mode.

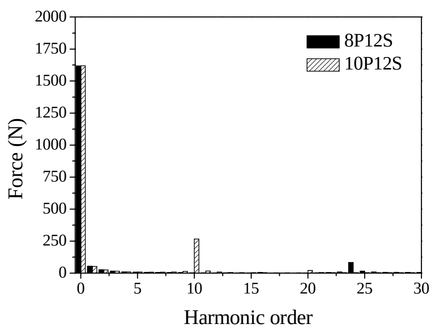


(a) No eccentricity *(b) Stator static eccentricity*

Fig. 3. Radial force distribution

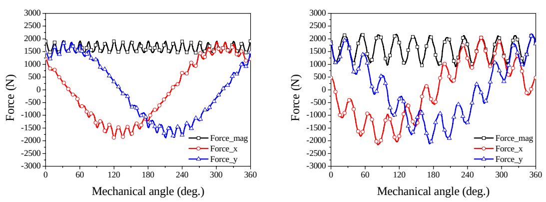


(a) 8 pole-12 slot *(b) 10 pole-12 slot*

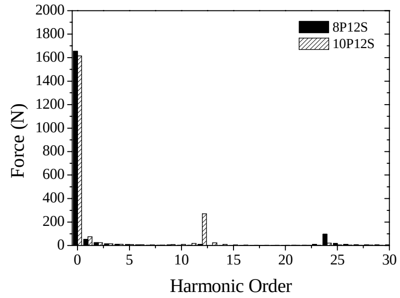


(c) Harmonic components

Fig. 4. Unbalanced force due to static eccentricity

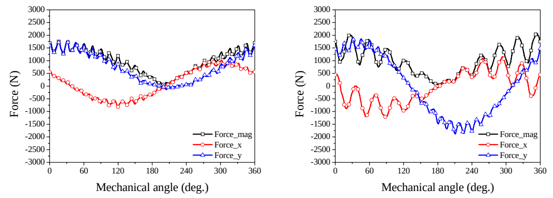


(a) 8 pole-12 slot *(b) 10 pole-12 slot*

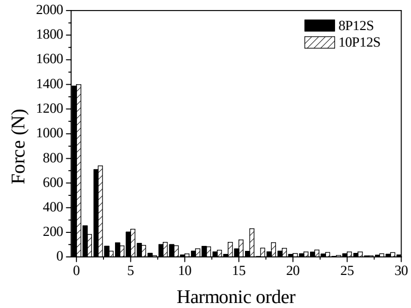


(c) Harmonic components

Fig. 5. Unbalanced force due to dynamic eccentricity



(a) 8 pole-12slot machine *(b) 10 pole-12 slot machine*



(c) Harmonic Components

Fig. 6. Unbalanced force due to mixed eccentricity

IV. ACKNOWLEDGEMENTS

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V. REFERENCES

[1] T.J.E Miller, Design of Brushless Permanent Magnet Motor, Clarendo press, Oxford, 1994

[2] Z.Q. Zhu, Dahaman Ishak, David Howe, and Jintao Chen, “Unbalanced Magnetic Forces in Permanent-Magnet Brushless Machines With Diametrically Asymmetric Phase Windings,” *IEEE Trans. On Industry Applications*, vol. 43, no. 6, pp. 1544-1553, 2007.

[3] Z.Q. Zhu, Z.P. Xia, L.J. Wu, and Geraint W. Jewell, “Analytical Modeling and Finite-Element Computation of Radial Vibration Force in Fractional-Slot Permanent-Magnet Brushless Machines,” *IEEE Trans. On Industry Applications*, vol. 46, no. 5, pp. 1908-1918, 2010.

[4] Taeyong Yoon, “Magnetically Induced Vibration in a Permanent – Magnet Brushless DC Motor with Symmetric Pole-Slot Configuration,” *IEEE Trans. On Magnetics*, vol. 41, no. 6, pp. 2173-2179, 2005.

[5] David G. Dorrell, Mircea Popsescu, and Dan M. Ionel, “Unbalanced Magnetic Pull Due to Asymmetry and Low-Level Static Rotor Eccentricity in Fractional-Slot Brushless Permanent-Magnet Motors With Surface-Magnet and Consequent-Pole Rotors, IEEE Trans. On Magnetics, vol 46, no. 7, pp.2675-2685, 2010.